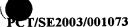10   A vehicle and a method for controlling steering thereof

FIELD OF THE INVENTION AND PRIOR ART

15   The present invention relates to a vehicle and a method for
controlling thereof according to the pre-characterizing part of
the attached independent vehicle and method claims
respectively.

The vehicle can be of many different types, and the invention
20   includes both driver controlled as well as driver-less, remote
controlled vehicles. The invention is however in particular, but
not exclusively, directed towards vehicles which will move in en-
vironments where space is relatively limited and where high de-
mands are placed on the vehicles' manoeuvrability, as is the
25   case for industrial trucks, which are driven in warehouses, in-
dustrial sites, loading yards and other such places to handle
cargo. For this reason the invention will hereafter mainly be de-
scribed in connection with vehicles of such so-called truck type
without limiting the invention in any way thereto.
30
A vehicle of the type defined by way of introduction is known
from the applicant's patent application PCT/SE99/00618. By ar-
ranging said two first wheels in the indicated way excellent
properties to displace such a vehicle in a confined space ac-
35   cording to advantageous movement patterns are achieved. The
reason for this is that it can be said that such a wheel can be

turned on the spot without any tendency to slip in that on turning the wheel one revolution around the first axis it will with said turning point describe a circle on the ground. At the same time it is made possible to take up new alignments of the wheel while the chassis is totally still, which means that the vehicle can be brought to a new position in the shortest possible or otherwise most desirable way.

It is stated here that the invention is fully realisable with only said first wheels of said first type and no other means resting on the ground to support the chassis, so that in this case the vehicle has to be balanced like a motorcycle, even if hereafter the diagrams and the accompanying text show and describe the case of a vehicle with four wheels, as this is the way the vehicle will usually be realised. The desire exists to improve the way in which the vehicle of the discussed type is controlled in order to make full use of the excellent possibilities of displacement patterns which such a vehicle offers.

SUMMARY OF THE INVENTION

The aim of the present invention is to provide a vehicle and a method for controlling thereof which make it possible to fulfil said desire.

This aim is achieved by providing a regulation device which is designed with the capability to, on request of the change of the vehicle's direction in horizontal plane, order a location for a turning point for the vehicle located anywhere in the horizontal plane, the control device's calculation unit is designed to calculate the instantaneous desired value of respective said first wheel's angular alignment relative to a longitudinal axis of the vehicle corresponding to the location of said turning point as ordered by the regulation device and send signals to the control means so as to achieve that alignment.

With such a design of the regulation device and the control device of the vehicle arbitrary movement patterns of the vehicle can be achieved by simple means. If the vehicle is displaced without any change in its direction in the horizontal plane, i.e.

5   according to a translational movement, then it is driven in a conventional way with the wheels in parallel alignment with each other, but if a direction change of the vehicle is required, then an arbitrary location of the vehicle's swinging point or turning point can be ordered by the regulation device and the direction

10 change can then be achieved by turning the vehicle around the ordered turning point by the control device. This can accordingly be located anywhere in relation to the vehicle, for example it can be ordered to lie at the front edge of a fork of a vehicle in form of a forklift truck, so that the vehicle turns about the front edge

15 of the fork.

It is pointed out here that "calculate" as used in the patent claims is to be given a broad meaning, and that it is not necessary that the calculation unit carries out an actual calculation,

20 but it is even possible that it just "registers" what the regulation device orders and forwards desired values depending upon this registration to the control means. It is even possible that value tables are stored in advance in the calculation unit to carry out the predetermined control of the wheels on receipt of a certain

25 order from the regulation device, but in most cases an optional, step-free control with an infinite number of possible alignments and the possibility of absolute precision is preferred.

According to a preferred embodiment of the invention the cal-

30 culation unit is designed to assume an alignment of said first wheels about the first axis parallel to each other on calculation of the desired value for each wheel alignment in the horizontal plane for a determined position of the said turning point to determine each wheel's turning about said first axis relative to

35 said parallel alignment. By assuming a determined parallel alignment of the wheels relative to one another in said

calculations (defined as above), the individual wheels' turning to turn the vehicle around an ordered turning point can be decided in an excellently simple way. This even makes it possible to simply return to the parallel alignment when so desired and it is

5   especially advantageous to design the calculation unit to select the alignment that the vehicle's wheels had as the last parallel alignment before the regulation device's ordering of a said alignment change as the assumed parallel alignment in its calculations, which is the object for a further preferred

10   embodiment of the invention. This simplifies the calculations and facilitates the return to the initial parallel alignment of the wheels.

According to another preferred embodiment of the invention the

15   calculation unit is designed to establish a Cartesian co-ordinate system in the horizontal plane for its calculations with the chassis' centre of rotation as origin and to utilise the co-ordinate for said location of the vehicle's turning point in said co-ordinate system in the calculation of said alignment of each said first

20   wheel, and it is then especially advantageous if the calculation unit is arranged to designate an axis in said Cartesian co-ordinate system to be directed parallel to said assumed parallel alignment. This then means that in the above-mentioned case of selecting the last parallel alignment as the assumed parallel

25   alignment if this parallel alignment was not in the vehicle's longitudinal direction the co-ordinate system will be turned relative to the vehicle's longitudinal direction to facilitate the calculation.

30   According to another preferred embodiment of the invention the regulation device comprises a first means to order a parallel displacement of the vehicle's steering line, i.e. the intended line that intersects said turning point and extends perpendicularly to said assumed parallel alignment, and according to another em-

35   bodiment the regulation device comprises a second means to displace the turning point ordered by the regulation device along

with the instantaneously existing steering line of the vehicle, which in practice means that the vehicle's swinging radius is changed. It is thereby advantageous to have the first and second means controllable totally independently of one another, so
5   that by manoeuvring these the ordered turning point can be decided at an arbitrary location in said co-ordinate system and thereby the horizontal plane.

The invention even relates to a method according to the at-
10   tached independent method claims. The properties and advantages of this together with the methods according to the other attached method claims will be apparent from the above description of the corresponding vehicle patent claims.

15   The invention even relates to a computer program and a computer readable medium according to the corresponding attached patent claims. It is easily understandable that the method according to the invention defined in the attached set of patent claims is well suited to be carried out by program instructions
20   from a processor under the influence of a computer program provided with the program steps in question.

Other advantages as well as advantageous features of the invention are apparent from the other dependent patent claims as
25   well as the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, some preferred embodiments of the invention
30   are described as examples with reference to the attached drawings, in which:

Fig 1   is a view of a vehicle of the inventive type,

Fig 2   is a schematic view illustrating the general construction and function a said first wheel of such a vehicle,

5   Fig 3   schematically illustrates a possible parallel alignment of the wheels of the vehicle according to the invention,

Fig 4   illustrates a movement pattern achievable by a vehicle of the inventive type by parallel alignment of the wheels,

10

Figs 5 and 6 are schematic views of an inventive vehicle viewed from above illustrating how the control device calculates the wheel alignment for an ordered turning point location,

15

Fig 7   is a view illustrating an achievable movement pattern of the vehicle according to the invention using the control modes described with help of Figs 5 and 6,

20

Fig 8   illustrates a different movement pattern possible with the inventive vehicle,

25

Fig 9   illustrates very schematically how the steering line can be displaced relative to the vehicle and how the turning point can be displaced along a given steering line relative to the vehicle of a vehicle according to the invention,

30

Fig 10   schematically illustrates a possible embodiment of the means incorporated in the regulation device,

Fig 11   schematically illustrates another possible embodi-
              ment of means incorporated within the regulation
              device, and

5   Fig 12   illustrates very schematically the components,
              which are used in the control of a vehicle according
              to a preferred embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS
10   OF THE INVENTION

Fig 1 schematically illustrates the design of an inventive vehicle
1 in the form of an industrial truck with a driver seat F, a chassis
2 and first wheels of a first type connected to the chassis in the
15   vicinity of each corner of a rectangle in the horizontal plane.
Such a first wheel is shown in Fig 2 and is arranged to be ro-
tatable relative to the chassis not only about a first, substantially
vertical axis 4, but also about a second axis 5 which constitutes
an angle greater than 0° but less than 90°, here about 60°,
20   relative to the first axis. The wheel has a contact surface, which
forms a so-called turning point 6 against this, which is laterally
displaced in a horizontal plane relative to the first axis (region
A). This displacement of the turning point 6 relative to the first
axis 4 means that on one revolution of the wheel around the axis
25   a circle will be traced on the ground by the wheel's rolling point
6.

All four wheels are individually controllable as regards the turn-
ing around the first axis 4, while two of them, in the present
30   case both of the front wheels 3' are individually drivable (arbi-
trarily two, three or four of the wheels could be individually
drivable). This design of the wheels means that they can occupy
an arbitrary position while the chassis is totally still.

35   Fig 3 schematically illustrates how the wheels can for example
be aligned parallel with each other even if they are turned rela-

tive to the vehicle's lengthwise direction. The control device 7 incorporated in the vehicle (see Fig 12) is arranged to control said wheels via the control means 8 according to the basic principle that they should be mutually parallel-aligned on movement

5   of the vehicle in the horizontal plane with the exception of when
       a change in the vehicle's direction in the horizontal plane is ordered by the regulation device 9. This means that in order to get to a position which does not lie along the vehicle's lengthwise axis and in which the vehicle will have the same alignment as

10   that concerned the vehicle's alignment is not changed to drive towards the position and then changed back, as is necessary with conventional vehicles, but translational displacements of the vehicle between different points takes place in such cases without the demands of temporary alignment changes of the ve-

15   hicle, and an example of such displacements is shown in Fig 4, where the vehicle's movement direction is changed by changing the alignment of the mutually parallel aligned wheels relative to the vehicle's lengthwise direction. The sweep area 10 which the vehicle "shadows" as it drives forward over the indicated area is

20   marked with a dashed line. This sweep area defines a space which has to be free in order for the vehicle to move itself over the ground, and due to the inventive vehicle's design and control method a greater flexibility as regards the variation of this sweep area and possibilities to reduce it where the available

25   space is limited are achieved. This is especially important in the case of industrial trucks, which move over an industrial floor, where great cost can be saved by better utilization of the surfaces.

30   The crux of the present invention will now be described with simultaneous reference to Figs 5 and 6 and even Figs 9 to 12 to a certain degree.

       Fig 5 schematically illustrates an inventive vehicle with the
35   chassis' centre of rotation C as the origin in a Cartesian co-ordinate system of a calculation unit 11 of the control device for

alignment of the wheels on the basis of orders from the regula-
tion device 9. The calculation unit is arranged to assume an
alignment of the wheels about their fist axes parallel with one
another on calculation of desired values for each wheel's align-
5   ment in the horizontal plane for a determined location of a cho-
       sen turning point to determine each wheel's turning about the
first axis relative to the parallel alignment. The co-ordinate sys-
tem is thereby applied so that an axis (here the X-axis) is di-
rected parallel to said assumed parallel alignment. This as-
10   sumed parallel alignment can be arbitrarily chosen by the con-
trol device, but the parallel alignment which the vehicle's wheels
just have is preferably chosen for this, when an alignment
change, i.e. swinging, of the vehicle will be initiated. In Fig 5 the
assumed parallel alignment is in agreement with the vehicle's
15   lengthwise axis, while Fig 6 illustrates how the assumed parallel
alignment constitutes an angle θ, so in Fig 5 θ is therefore equal
to zero.

The vehicle's steering line S is defined as the intended line
20   which intersects the ordered turning point B and extends per-
pendicularly towards the assumed parallel alignment that the
calculations are based upon, i.e. the X-axis. The wheels are
aligned so that the horizontal projection of their second axes
intersect each other at turning point B, and in a conventional
25   vehicle with only two controllable wheels said steering line
therefore always coincides with the axis of both of the uncon-
trolled wheels. In the inventive vehicle the turning point B and
the steering line S can however be positioned arbitrarily.

30   It will now be explained with reference to mainly Figs 9 to 11
how the order concerning the location of the turning point B
relative to the vehicle can be given via a regulation device of the
vehicle. The regulation device comprises first means to order a
parallel displacement of the vehicle's steering line S, i.e. along
35   the X-axis in the way that is indicated in Fig 9 by arrows and two
possible positions S' and S". At the same time there are other

means to order the displacement of the turning point along the instantaneously existing steering line of the vehicle, which are indicated with the line L and two possible alternative positions B_1 and B_2. If the turning point is displaced to infinity along the Y-axis, this means driving straight ahead, while the vehicle's swing radius becomes smaller the nearer it gets to the vehicle's centre of rotation.

Arbitrary locations for the vehicle's turning point B in the horizontal plane are ordered by said first and second means, of which some of the multitude of different possible variations are shown in Figs 10 and 11. Fig 10 illustrates how said first means 12 is constituted of a lever, in this case a parallel link system, which is movable along a scale 13, on which different locations of steering lines relative to the vehicle are indicated with lines 14. Another means in the form of a turnable steering wheel 15 for ordering of displacement of the turning point along a given steering line is rotatably mounted on the lever aggregate 12. It feels natural for a driver to have a turnable element for this function, because it influences the vehicle's swing radius. The regulation device comprises a further third means in the form of a lever 16 for alignment of the direction of rotation, forwards or backwards, of both of the controllable wheels. The regulation device also has a fourth means in the form of an accelerator 17 to order the speed to the drive means 18 (see Fig 12) to drive both of the controllable wheels.

Fig 11 illustrates alternative embodiments of the means of the regulation device, and here the means for displacement of the vehicles steering lines, here in the form of a sliding bolt 12', physically separated (in Fig 10 it is only functionally separated) relative to the means for displacement of the turning point along a steering line, which even has a steering wheel 15', on which a tilting lever 16' is arranged to set the driving forwards or backwards.

When a location is ordered via the regulation device signals are sent to the control device 7 which assuming said assumed parallel alignment of the wheels calculates a desired value of the alignment of each individual wheel relative to the vehicle's lengthwise axis, see the angles φ_1-φ_4, to control the wheels at these angles via the control means 8. These calculations take place according to the equations given below for the respective angle, where the different parameters are shown in Fig 6:

$$\varphi_1 = \Theta + \operatorname{atan}\left(\frac{h_1 + x}{y - s_1}\right), \text{ with } s_1 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \sin\left(\beta + \Theta\right)$$

$$h_1 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \cos\left(\beta + \Theta\right)$$

$$\varphi_2 = \Theta + \operatorname{atan}\left(\frac{h_2 + x}{y + s_2}\right), \text{ with } s_2 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \sin\left(\beta - \Theta\right)$$

$$h_2 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \cos\left(\beta - \Theta\right)$$

$$\varphi_3 = \Theta + \operatorname{atan}\left(\frac{h_3 - x}{y + s_3}\right), \text{ with } s_3 = \sqrt{s'_2{}^2 + h'_2{}^2} \bullet \sin\left(\beta + \Theta\right)$$

$$h_3 = \sqrt{s'_2{}^2 + h'_2{}^2} \bullet \cos\left(\beta + \Theta\right)$$

$$\varphi_4 = \Theta + \operatorname{atan}\left(\frac{h_4 - x}{y - s_4}\right), \text{ with } s_1 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \sin\left(\beta - \Theta\right)$$

$$h_1 = \sqrt{s'_1{}^2 + h'_1{}^2} \bullet \cos\left(\beta - \Theta\right)$$

where h_1' and h_4' are the wheel base and s_1' and s_2' are the track gauge, while the corresponding h_1 and h_4 and s_1 and s_2 respectively are the values which are used for these for the cal-

culations when the co-ordinate system is turned through angle θ relative to the vehicles lengthwise axis. θ is therefore positive on clockwise turning and negative on anti-clockwise turning of the co-ordinate system. θ is therefore negative in Fig 6. x and y
5   are the co-ordinates for the turning point B in the co-ordinate
     system.

The control device is preferably even arranged to calculate a suitable velocity of rotation of the wheel about its second axis
10   via its calculation unit for each said first turnable wheel from the wheels distance from said turning point B in co-operation with the fourth means 17. A clean and economical course for each drive wheel can thereby be achieved. The undriven wheels automatically get the correct speed. The speed of the driven
15   wheels is calculated thereby according to the following:

$$V_1 = \dot{\varphi}\ \frac{h_1 + x}{\sin\varphi_1}$$

20

$$V_2 = \dot{\varphi}\ \frac{h_2 + x}{\sin\varphi_2}$$

25

$$V_3 = \dot{\varphi}\ \frac{h_3 - x}{\sin\varphi_3}$$

$$V_4 = \dot{\varphi}\ \frac{h_4 - x}{\sin\varphi_4}$$

30

35

where $\dot{\varphi}$ is the angular velocity of the vehicles swinging about the turning point, and this is therefore the same for all parts of the vehicle. In embodiment shown the wheels with φ_3 and φ_4, and therefore with the speeds v_3 and v_4, are used as the driving

5   wheels.

The vehicle even exhibits means 19 (see Fig 12) to sense the rotational velocity and direction of rotation of the drive wheels and means 20 to sense the respective wheels actual angle rela-

10   tive to the vehicles lengthwise axis to send the values of the sensed parameters to the control device 7 in order for the means 21 incorporated therein to compare the results of said sensing with the corresponding desired values ordered by the calculation units calculations, and the control device is arranged

15   to correct the control signals to the control means 8 and drive means 18 to achieve agreement between the results and the desired values in the event of deviation between said results and desired values.

20   It is clear from the above that it is advantageous that the control device is constituted of a programmable computer, that can therefore be reprogrammed if necessary.

Figs 7 and 8 show two of the infinitely many movement patterns

25   that are achievable with a vehicle according to the present invention, which cannot be achieved with a conventional vehicle. In Fig 7 the truck's driver firstly orders a swinging of the truck around a turning point B_1 which lies in front of and at the side of the truck via the regulation device. After driving straight for-

30   wards towards a row 21 of loading pallets or such, the driver decides that it is suitable to swing the truck around a turning point B_2 located at the front edge of one of the forks 22 of the truck's lifting aggregate. The driver does not have to reverse and drive forward the truck a number of times in order to get into the right

35   position to lift the pallet in question, but can achieve this directly.

Fig 8 illustrates how it is possible with the inventive truck to drive along a straight line and at the same time rotate the truck, through 180° for example.

5

The invention is of course not in any way limited to the preferred embodiments described above, but a multitude of modification possibilities thereof should be apparent for a person skilled in the art, without him having to deviate from the basic idea of the

10   invention as defined in the appended claims for that reason.

For example in straightforward parallel driving the control at the wheels could be coupled together to take place via a single control means or in pairs via two.

15

As has already been mentioned the vehicle could exhibit a different number of wheels rather than four, for example such as two or three, and in a case with more than two wheels it is not necessary that the further wheels are of said first type. Instead

20   they could be of the link wheel type or be constituted of some other part with at least corresponding movability, which theoretically could be a part with a slideable support point that is substantially free relative to the ground in the horizontal plane, such as a part that utilizes an air cushion or such.

25

As regards the use of the word "horizontal" and "vertical" in this document in relation to the vehicle and its construction and control they refer to locations when the vehicle is resting on the horizontal surface, and axes and such are of course differently

30   directed on driving on a sloping surface or over obstructions.